Water Accounting Plus to empower reclaimed water in sustainable water balance

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1. Background

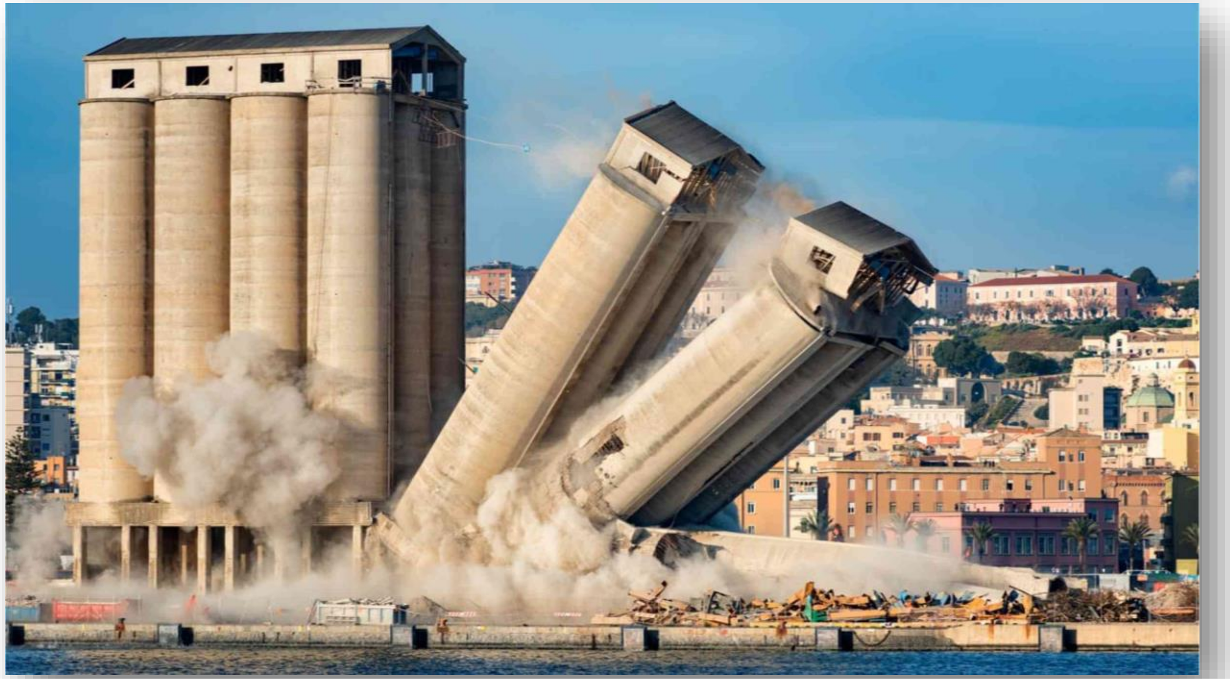
Water management challenges

- Different stakeholders, with different goals, different terms, and different information needs

1. Background

- Silos approach of management

"Traditionally, water quantity and quality have been managed separately" (Karimi et. al., 2024)

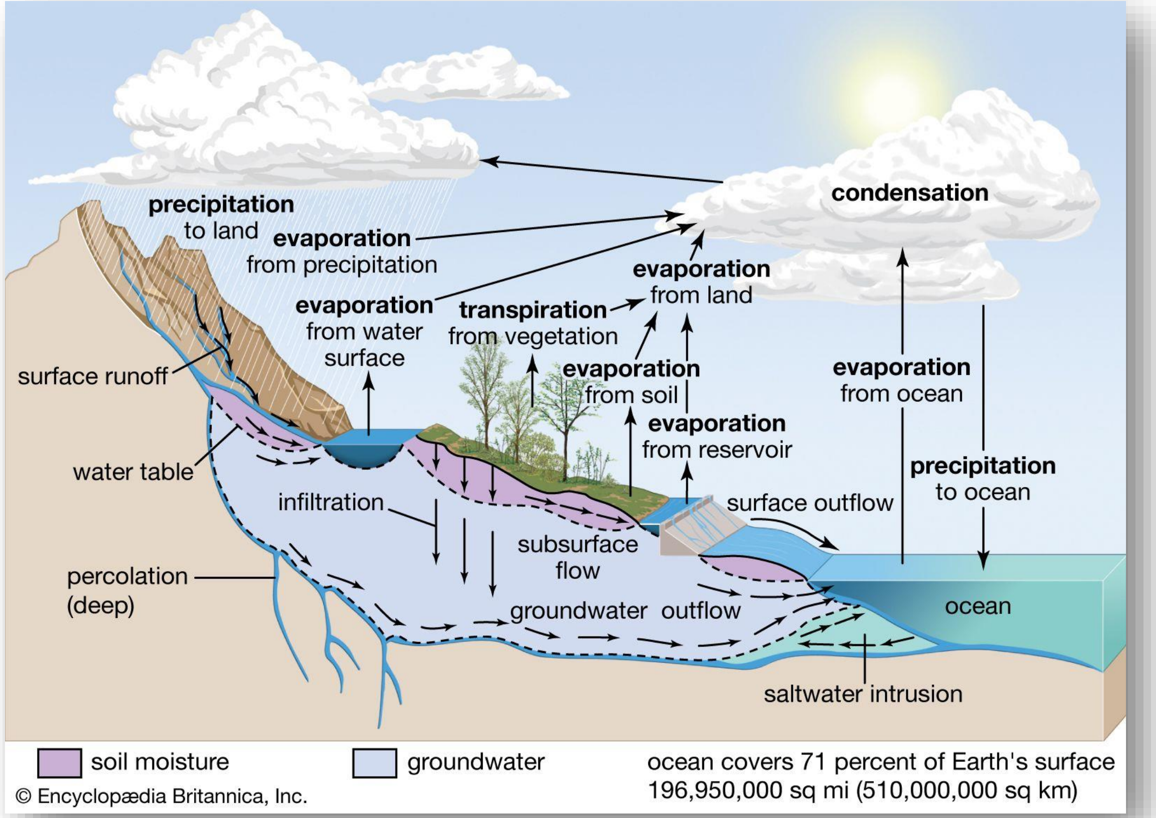


"Breaking silos takes time and energy, but it is worth it."

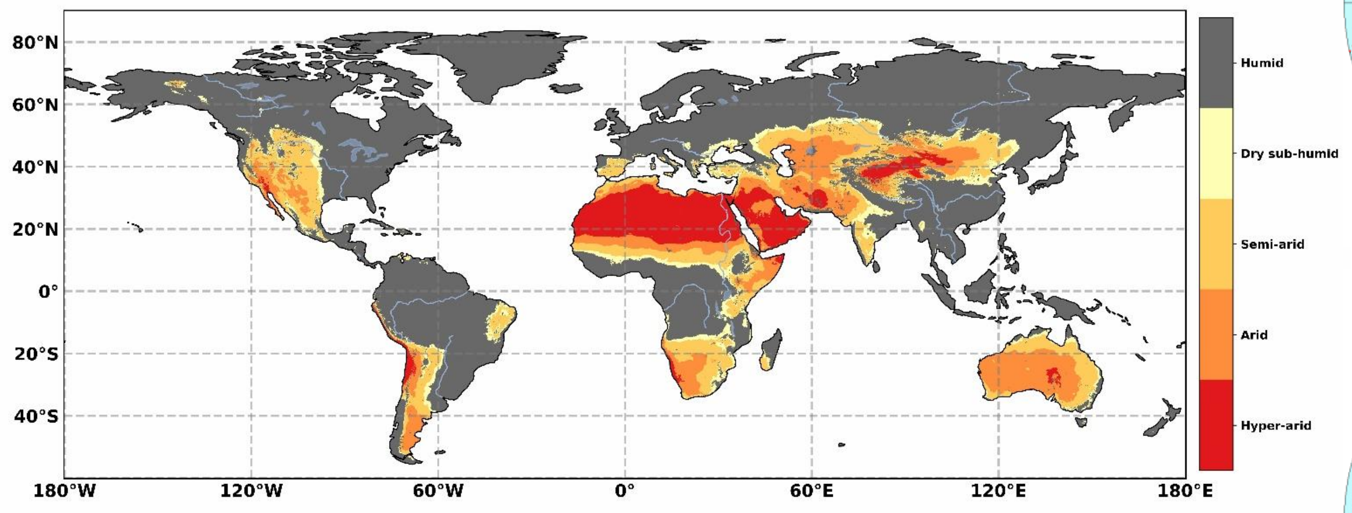
Peter Binder, Director-General of MeteoSwiss and the Swiss Permanent Representative to the World Meteorological Organisation (WMO)

1. Background

- Limited data

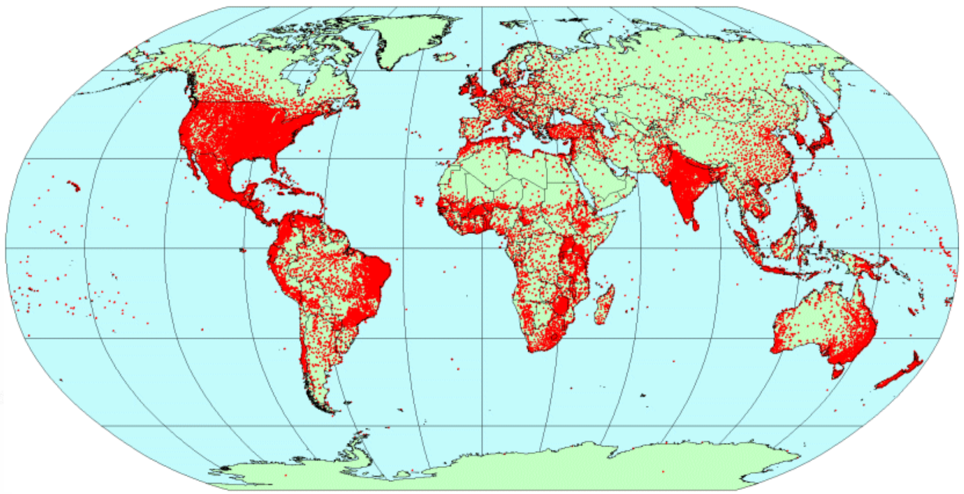


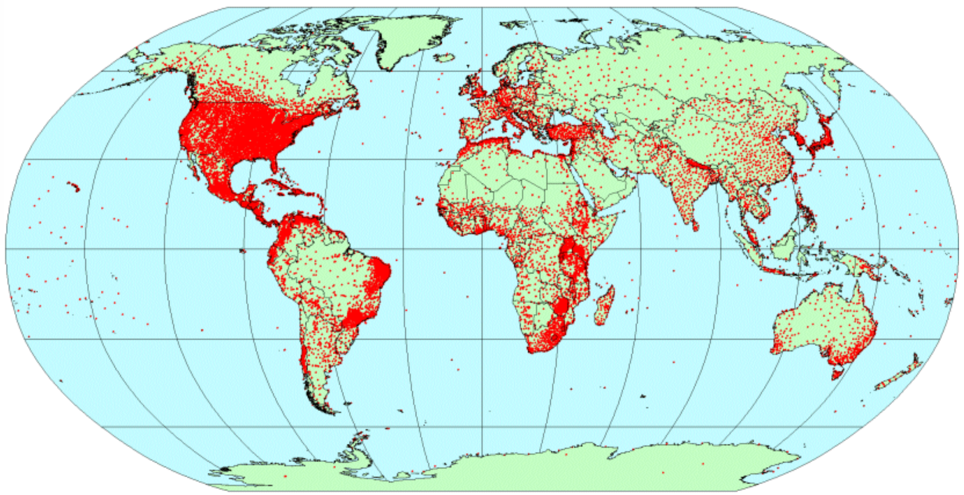
1. Background



Geographical distribution of arid lands

Rainfall

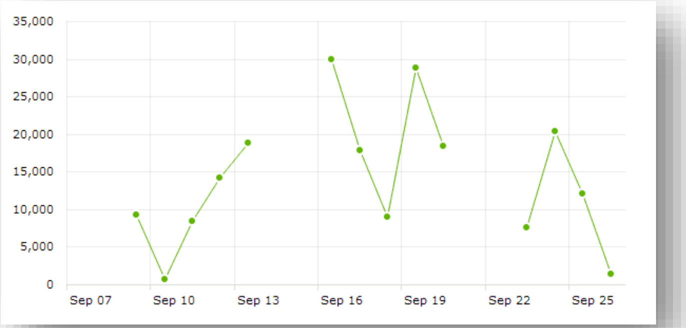




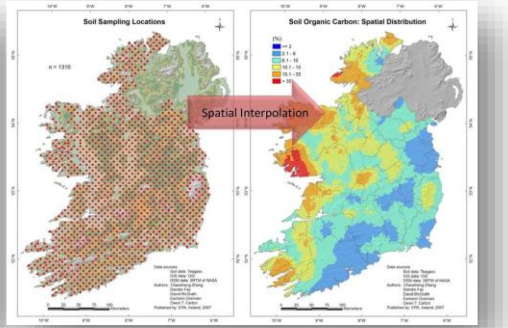
Temperature

1. Background

Sometimes, ground data are hard to obtain



Gaps in time series



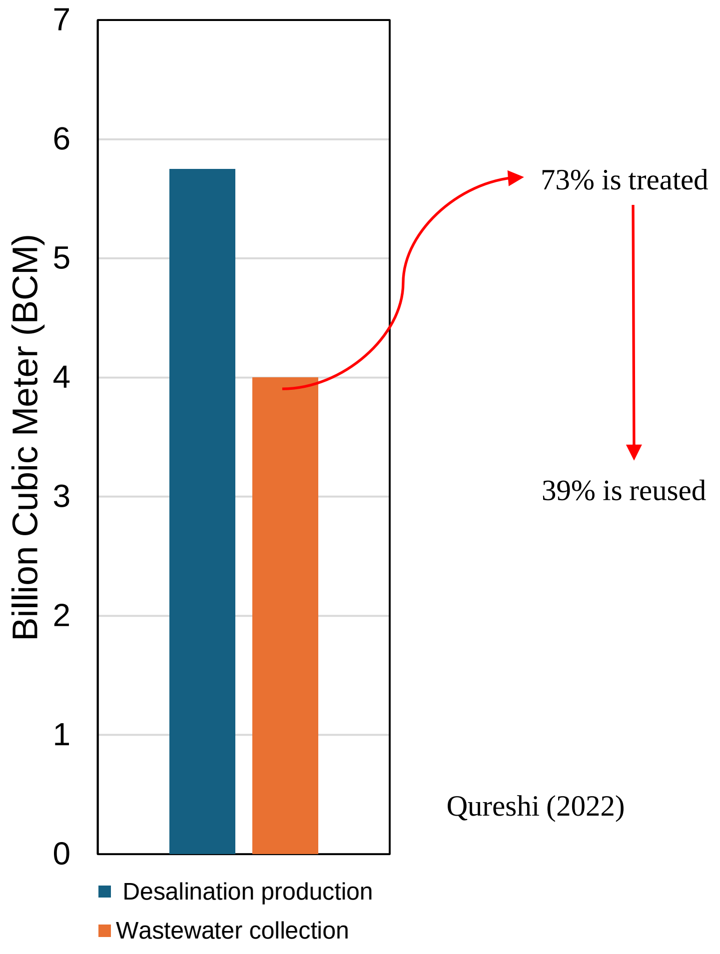
Lack of spatial dimension

1. Background

- Hidden opportunities and untapped potentials

  ✓ Massive opportunities in using treated wastewater in the GCC to reduce pressure on available water resources.

  ✓ While freshwater resources are becoming scarcer, treated wastewater is becoming more abundant. Therefore, discarding wastewater as an economic good has significant costs.

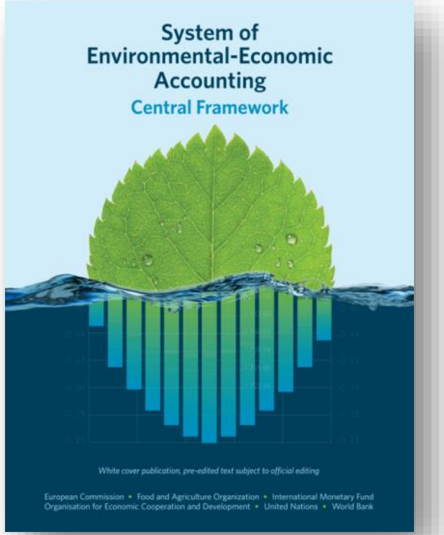


Qureshi (2022)

Standardized approaches that promote whole-water cycle understanding, integrated management and overcome data challenge is a key solution

1. Background

System of Environmental Economic Accounting for Water (SEEAW)

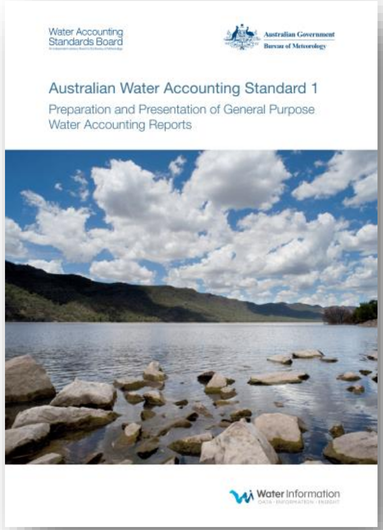


http://www.zaragoza.es/contenidos/medioambiente/onu//newsletter12/905-eng.pdf

FAO's Aquastat

http://www.fao.org/nr/water/aquastat/main/index.stm

3Water Accounting Standard of Australia.



http://www.bom.gov.au/water/standards/documents/awas1_v1.0.pdf

Water Accounting Plus (WA+)

http://www.wateraccounting.org/

Process	Low end performance description	High end performance description	WA+	SEEAW
	*	*****		
Field measurements involved	Few	Intensive	*	*****
Remote sensing measurements	No remote sensing	Intensive remote sensing	*****	**
Land use classes	Minimum attention	Maximum attention	*****	*
Economy	No attention	Maximum attention	*	***
Water quality	Not accounted for	Included	*	***
Temporal scale	Annual	Weekly	***	*
Consumptive use	Maximum attention	Minimum attention	*****	**
Hydrological cycle	A few terms only	All terms	*****	*
Natural vegetation	No attention	Fully explored	*****	*
Withdrawals general	Minimum attention	Maximum attention	****	*
Withdrawals domestic & industry	Minimum attention	Maximum attention	**	*****
Local reuse of water	No attention	Measured	*	*****
Return flow	Minimum attention	Maximum attention	****	**
Surface water	Not accounted for	Measured	***	****
Groundwater	Not accounted for	Estimated	***	**
Crop production	Detailed estimates	Not accounted for	*****	*
Crop water productivity	Not accounted for	Estimated	*****	*
Greenhouse gas emissions	Not accounted for	Estimated	****	*
Carbon sequestration	Not accounted for	Estimated	****	*
Ecosystem services	Detailed estimates	Not accounted for	*	****
Stocks (i.e. assets)	Not accounted for	Measured	***	****
Data consistency	Agency dependent	Single source	****	*
Access to results	Not accessible	Website with data	*****	**
Understanding	Complex	Simple	*****	**
Implementation	High efforts	Little efforts	*****	*
Communication tool	No	Yes	****	**

After Bastiannssen et al., 2015

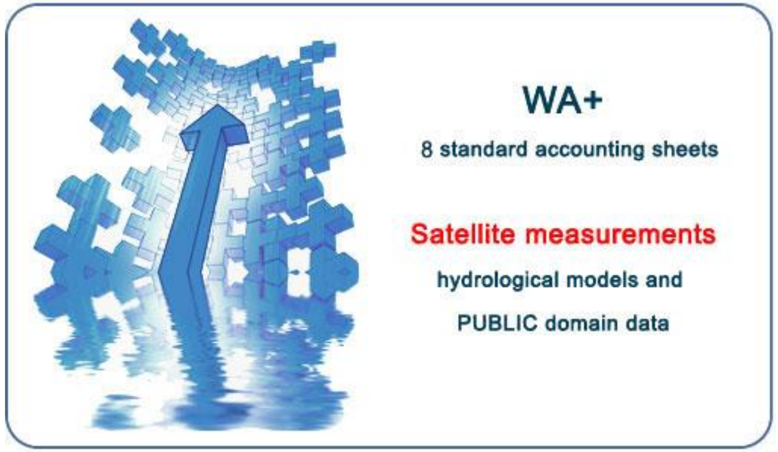
2. Water Accounting Plus (WA+)

- A Standard framework
- Promotes whole water cycle management
- Help navigating data challenge in data-scarce regions
- Can be implemented at different operational scales

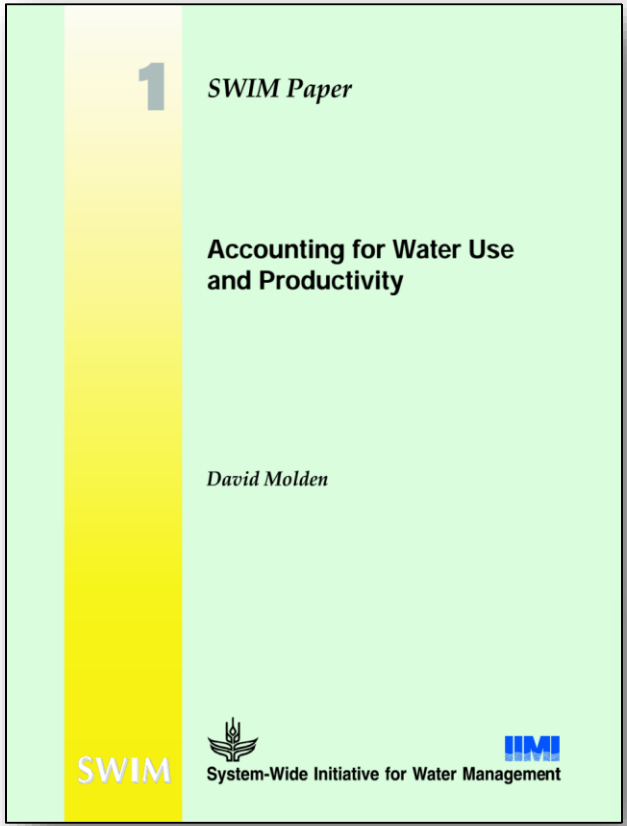
2. Water Accounting Plus (WA+)

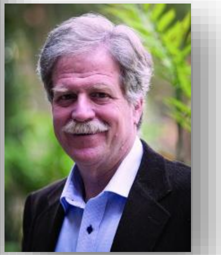
The ultimate goal of the WA is to

"track inflows, assets, liabilities, stocks and reserves for a particular area over a period of time" (Karimi et. al., 2013a, p. 1)

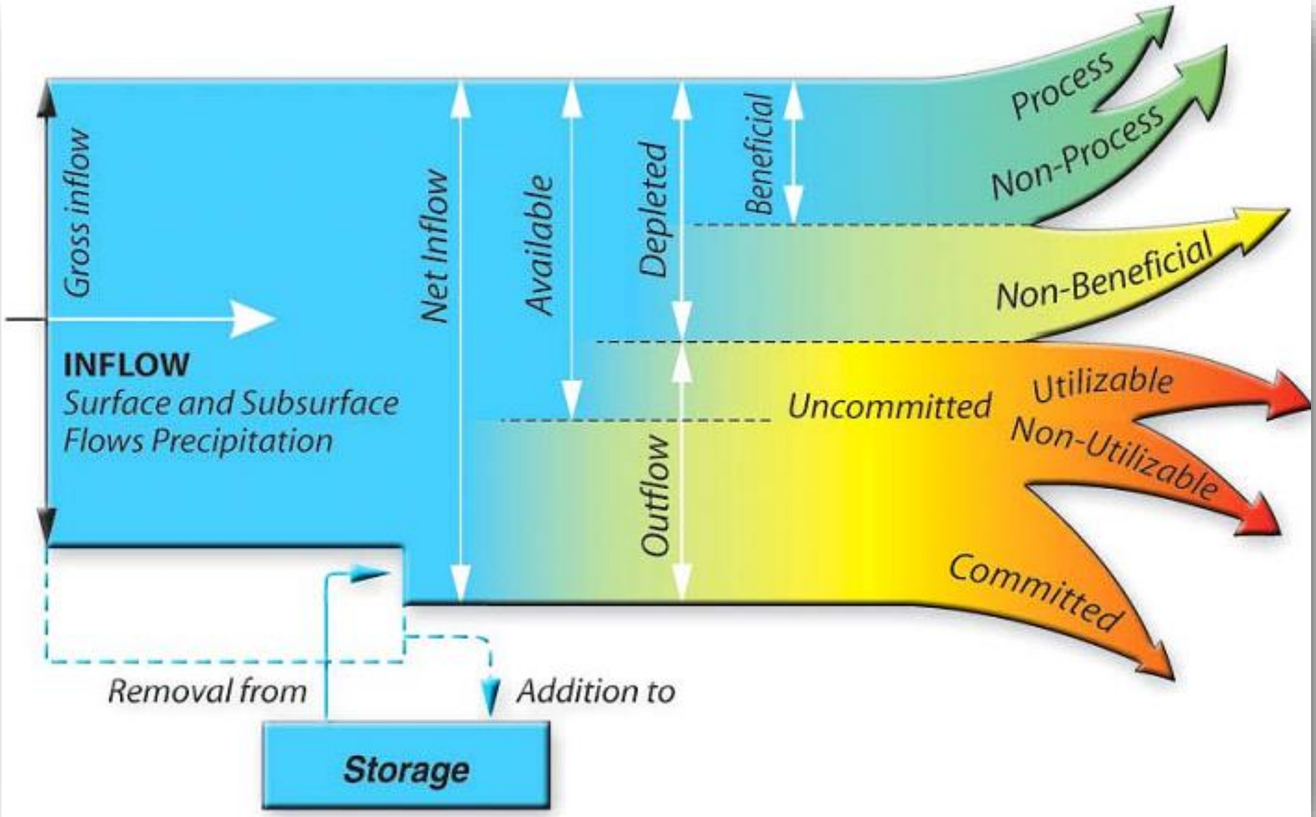


2. Water Accounting Plus (WA+)





D. Molden



Framework of Water Accounting (after Molden, 1997)

Molden, D. 1997. Accounting for water use and productivity. SWIM Paper 1. Colombo, Sri Lanka: International Irrigation Management Institute. Available online at: http://www.iwmi.cgiar.org/Publications/SWIM_Papers/PDFs/SWIM01.PDF

2. Water Accounting Plus (WA+)

Water Accounting Plus (WA+) – a water accounting procedure for complex river basins based on satellite measurements

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Abstract. Coping with water scarcity and growing competition for water among different sectors requires proper water management strategies and decision processes. A prerequisite is a clear understanding of the basin hydrological processes, manageable and unmanageable water flows, the interaction with land use and opportunities to mitigate the negative effects and increase the benefits of water depletion on society. Currently, water professionals do not have a common framework that links depletion to user groups of water and their benefits. The absence of a standard hydrological and water management summary is causing confusion and wrong decisions. The non-availability of water flow data is one of the underpinning reasons for not having operational water accounting systems for river basins in place. In this paper, we introduce Water Accounting Plus (WA+), which is a new framework designed to provide explicit spatial information on water depletion and net withdrawal processes in complex river basins. The influence of land use and landscape evapotranspiration on the water cycle is described explicitly by defining land use groups with common characteristics. WA+ presents four *sheets* including (i) a *resource base sheet*, (ii) an *evapotranspiration sheet*, (iii) a *productivity sheet*, and (iv) a *withdrawal sheet*. Every sheet encompasses a set of indicators that summarise the overall water resources situation. The impact of external (e.g., climate change) and internal influences (e.g., infrastructure building) can be estimated by studying the changes in these WA+ indicators. Satellite measurements can be used to acquire a vast amount of required data but is not a precondition for implementing WA+ framework. Data from hydrological models and water allocation models can also be used as inputs to WA+.

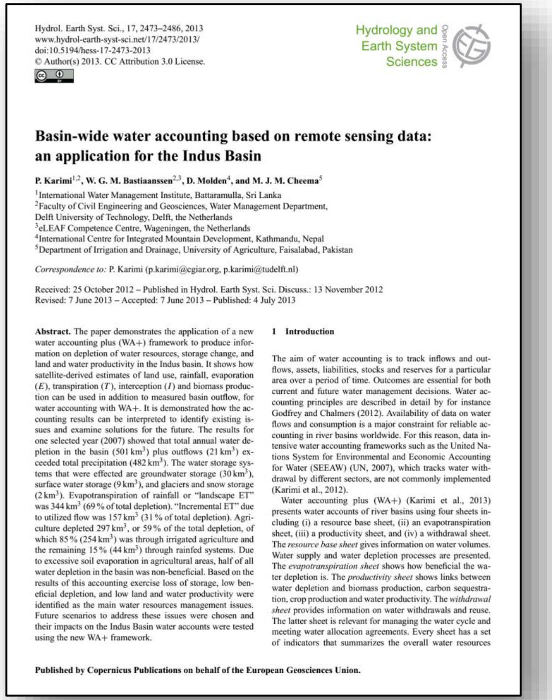
1 Introduction

Over the last 50 yr the world has changed from a situation of an abundance of water to a situation of water scarcity. Over 1.2 billion people live in basins where water demand is reaching, or has exceeded limits of sustainable use (Gleick, 2000; Molden, 2007; Rockström et al., 2009; World Health Organization (http://www.who.int/water_sanitation_health/hygiene/en/)). Population growth, changing diets, and economic growth, are some of the main causes of increased water use, which has resulted in competition for water, closed basins (a basin where all available water is depleted), overexploited groundwater resources, degraded land, reduced ecosystem services and anthropologically induced droughts. People have been quite proficient in changing land and water management practices and in modifying river flows to exploit water, also from aquifers. However, the era has now arrived that we need to communicate multi-sectorally for developing joint visions and targets for sustainable water and environmental management.

Our water institutions have been less effective in managing water in this relatively new era of scarcity, and this leads to a decline in the per capita water availability in various

Published by Copernicus Publications on behalf of the European Geosciences Union.

Karimi P., Bastiaansses W. g., and Molden D., 2013a. Water accounting plus (WA+) – a water accounting procedure for complex river basins based on satellite measurements. Hydrology and Earth System Sciences, 17, 2459-2472.



Hydrol. Earth Syst. Sci., 17, 2473–2486, 2013
www.hydrol-earth-syst-sci.net/17/2473/2013/
doi:10.5194/hess-17-2473-2013

Hydrology and Earth System Sciences
Open Access

Basin-wide water accounting based on remote sensing data: an application for the Indus Basin

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Abstract. The paper demonstrates the application of a new water accounting plus (WA+) framework to produce information on depletion of water resources, storage change, and land and water productivity in the Indus basin. It shows how satellite-derived estimates of land use, rainfall, evaporation (E), transpiration (T), interception (I) and biomass production can be used in addition to measured basin outflow, for water accounting with WA+. It is demonstrated how the accounting results can be interpreted to identify existing issues and examine solutions for the future. The results for one selected year (2007) showed that total annual water depletion in the basin (501 km^3) plus outflows (21 km^3) exceeded total precipitation (482 km^3). The water storage systems that were effected are groundwater storage (30 km^3), surface water storage (9 km^3), and glaciers and snow storage (2 km^3). Evapotranspiration of rainfall or "landscape ET" was 344 km^3 (69 % of total depletion). "Incremental ET" due to utilized flow was 157 km^3 (31 % of total depletion). Agriculture depleted 297 km^3, or 59 % of the total depletion, of which 85 % (254 km^3) was through irrigated agriculture and the remaining 15 % (44 km^3) through rainfed systems. Due to excessive soil evaporation in agricultural areas, half of all water depletion in the basin was non-beneficial. Based on the results of this accounting exercise loss of storage, low beneficial depletion, and low land and water productivity were identified as the main water resources management issues. Future scenarios to address these issues were chosen and their impacts on the Indus Basin water accounts were tested using the new WA+ framework.

1 Introduction

The aim of water accounting is to track inflows and outflows, assets, liabilities, stocks and reserves for a particular area over a period of time. Outcomes are essential for both current and future water management decisions. Water accounting principles are described in detail by for instance Godfrey and Chalmers (2012). Availability of data on water flows and consumption is a major constraint for reliable accounting in river basins worldwide. For this reason, data intensive water accounting frameworks such as the United Nations System for Environmental and Economic Accounting for Water (SEEAW) (UN, 2007), which tracks water withdrawal by different sectors, are not commonly implemented (Karimi et al., 2012).

Water accounting plus (WA+) (Karimi et al., 2013) presents water accounts of river basins using four sheets including (i) a resource base sheet, (ii) an evapotranspiration sheet, (iii) a productivity sheet, and (iv) a withdrawal sheet. The *resource base sheet* gives information on water volumes. Water supply and water depletion processes are presented. The *evapotranspiration sheet* shows how beneficial the water depletion is. The *productivity sheet* shows links between water depletion and biomass production, carbon sequestration, crop production and water productivity. The *withdrawal sheet* provides information on water withdrawals and reuse. The latter sheet is relevant for managing the water cycle and meeting water allocation agreements. Every sheet has a set of indicators that summarizes the overall water resources

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Karimi P., Bastiaanssen W., Molden D., and M. J. M. Cheema M., 2013b. Basin-wide water accounting based on remote sensing data: an application for the Indus Basin. Hydrology and Earth System Science, 17, 2473–2486.

P. Karimi

W. Bastiaanssen

D. Molden

M. J. M., Cheema

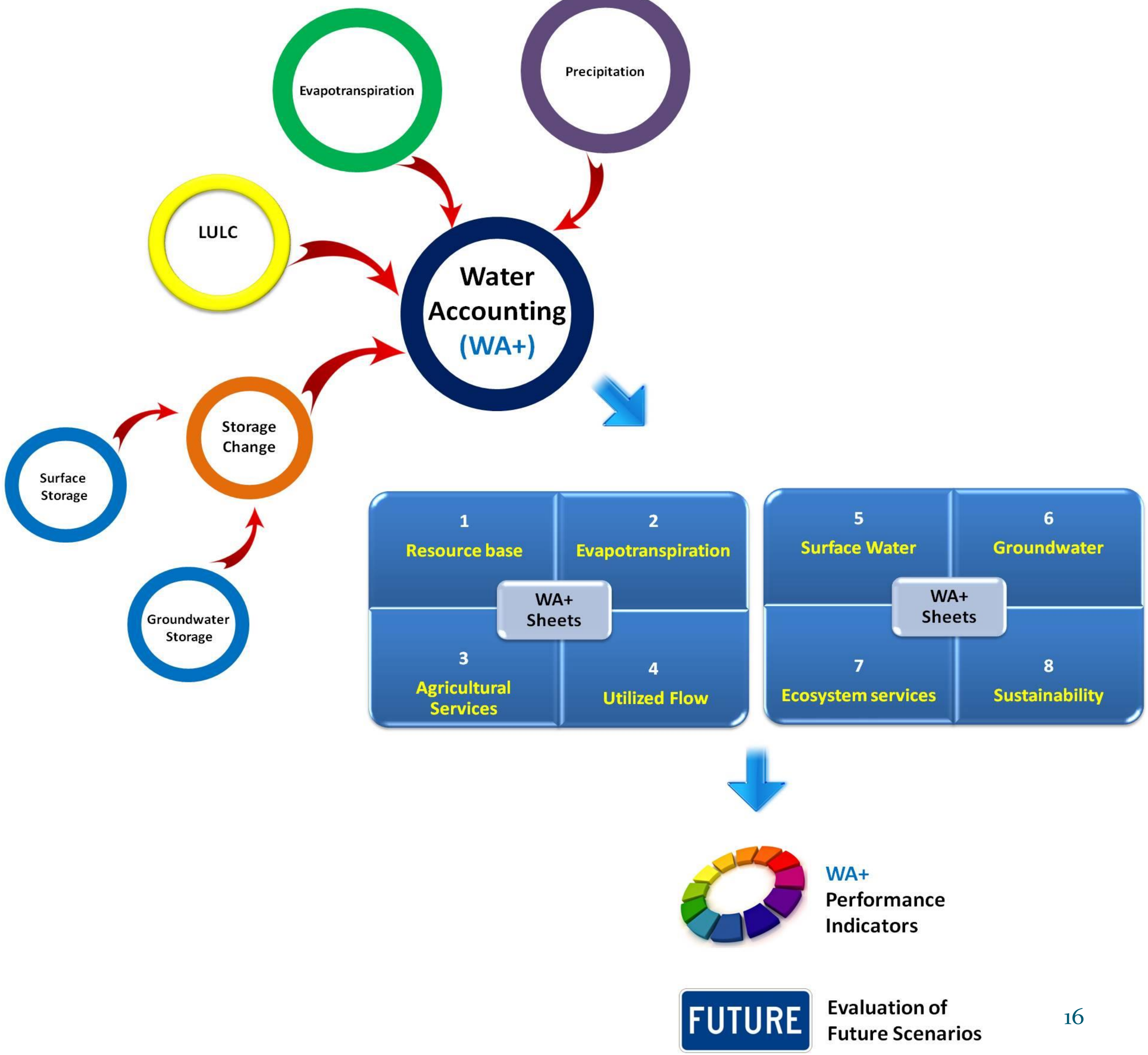
2. Water Accounting Plus (WA+)

$$\Delta S = P - ET - Q - R$$

Where:
ΔS is the change in storage in soil,
P is precipitation,
Q is runoff,
ET is evapotranspiration and
R is the average catchment recharge

- The classical approach of estimating the water balance is by using ground-based measurement for these parameters (Oki et. al., 1995).

- WA+ uses public-domain remote sensing data.

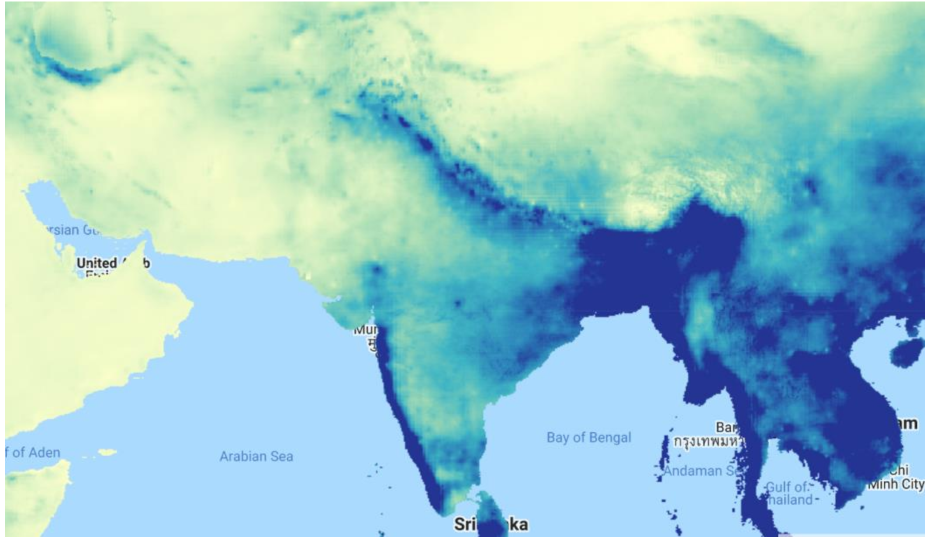

Evapotranspiration
Precipitation
LULC
Water Accounting (WA+)
Storage Change
Surface Storage
Groundwater Storage
1 Resource base
2 Evapotranspiration
WA+ Sheets
3 Agricultural Services
4 Utilized Flow
5 Surface Water
6 Groundwater
WA+ Sheets
7 Ecosystem services
8 Sustainability
WA+ Performance Indicators
FUTURE
Evaluation of Future Scenarios

2. Water Accounting Plus (WA+)

Advantages of WA+

1. Using public domain remote sensing data, which offers a way for standardized and transparent framework for data collection (Karimi et. al., 2013a).

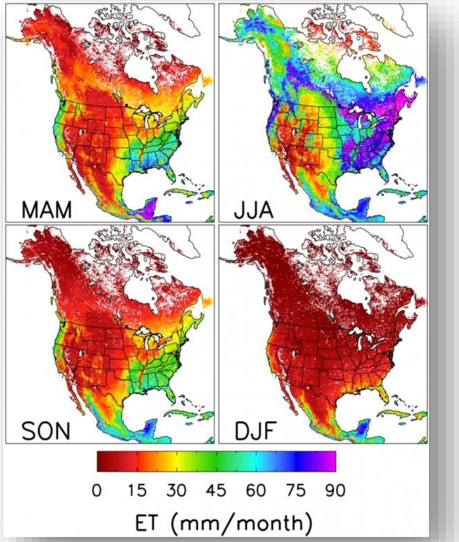
CHIRPS (Precipitation)



Climate Hazards Center, UC Santa Barbara

https://www.chc.ucsb.edu/data/chirps

MOD16 (Evapotranspiration)



NASA/EOS project

http://www.ntsg.umt.edu/project/mod16

2. Water Accounting Plus (WA+)

2. The major advantage of the WA+ approach is that water balance could be estimated for areas with limited or no ground-based data

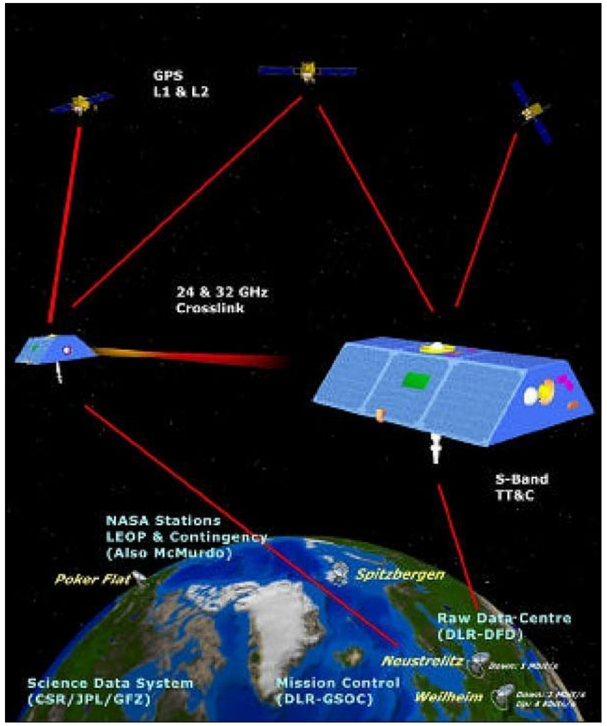
The water accounting information can be used for further analysis, for instance:

- Climate change
- Land cover/land use change
- Water Management
- Develop unconventional water resources

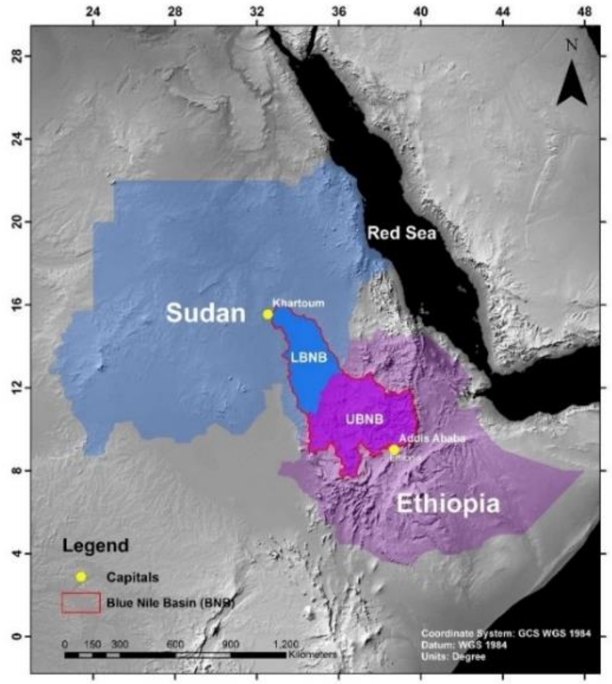
WA+ Procedure

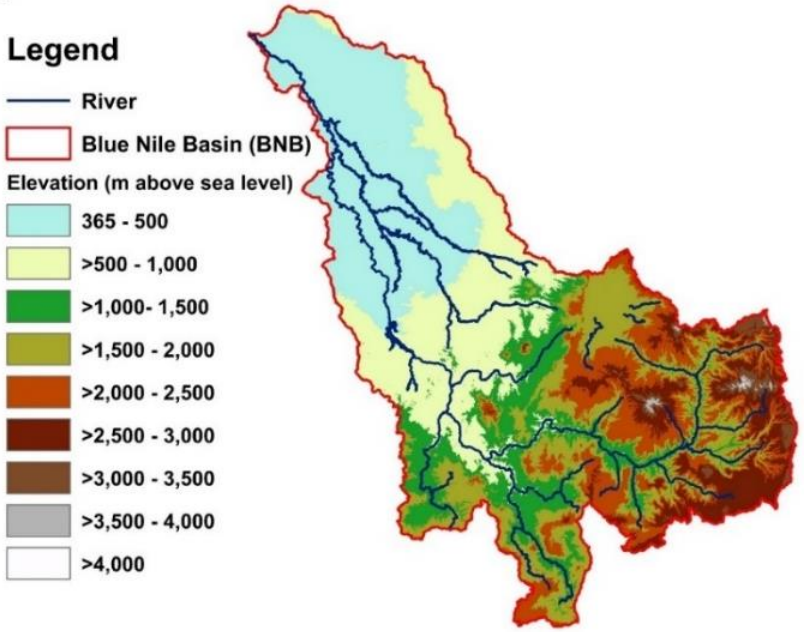
- 1. Select the most suitable datasets

No.	Factor	Source	Spatial coverage
1	Precipitation	TRMM	Global
		GPM	Global
2	Evapotranspiration	MOD16	Global
3	Soil Moisture	SMAP	Global
4	Runoff/stream flow	GLDAS	Global
5	Groundwater storage	GRACE	Global
6	Reservoir and lake level height	Jason-2	Global



Case study: Rainfall over the Blue Nile Basin

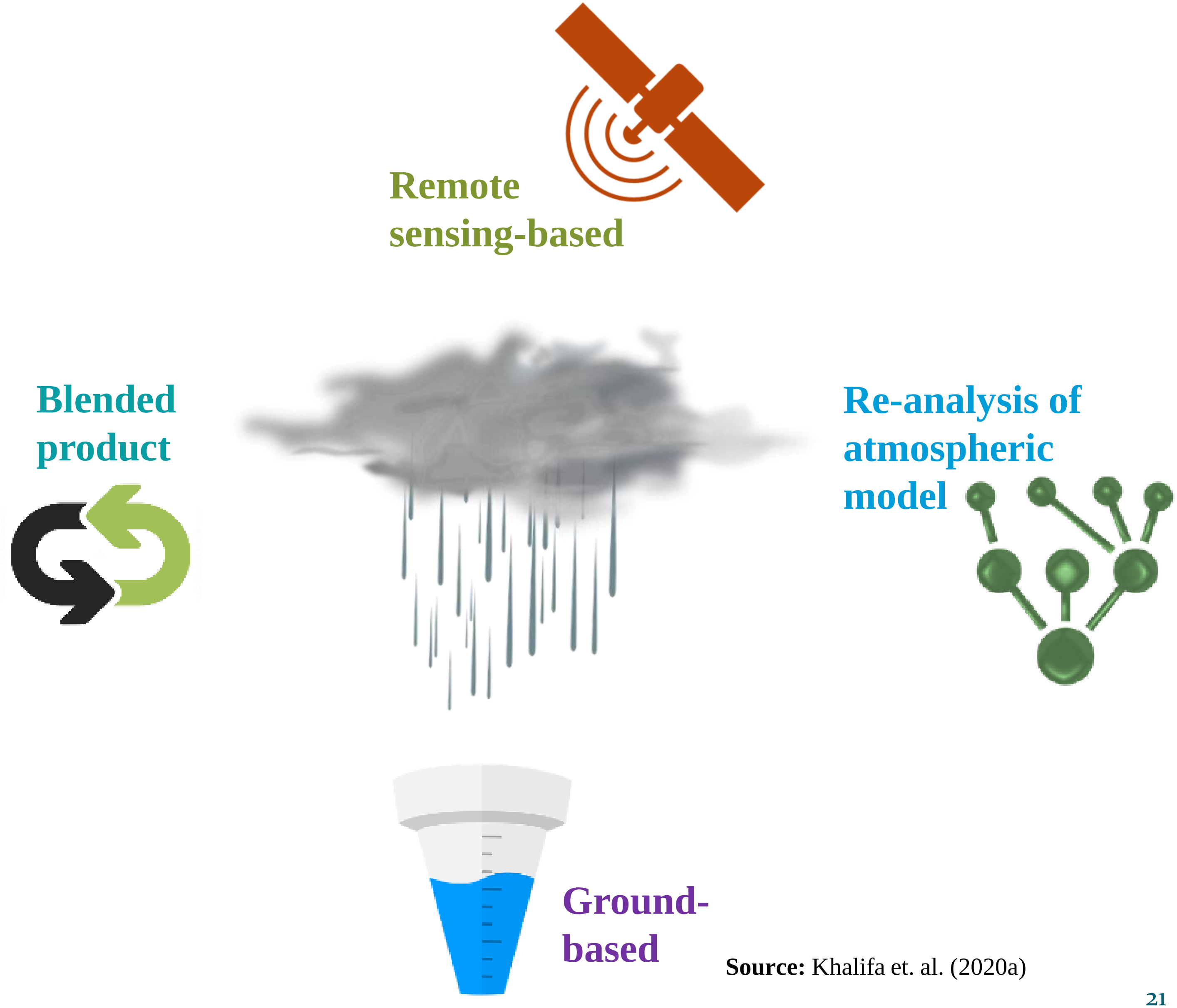




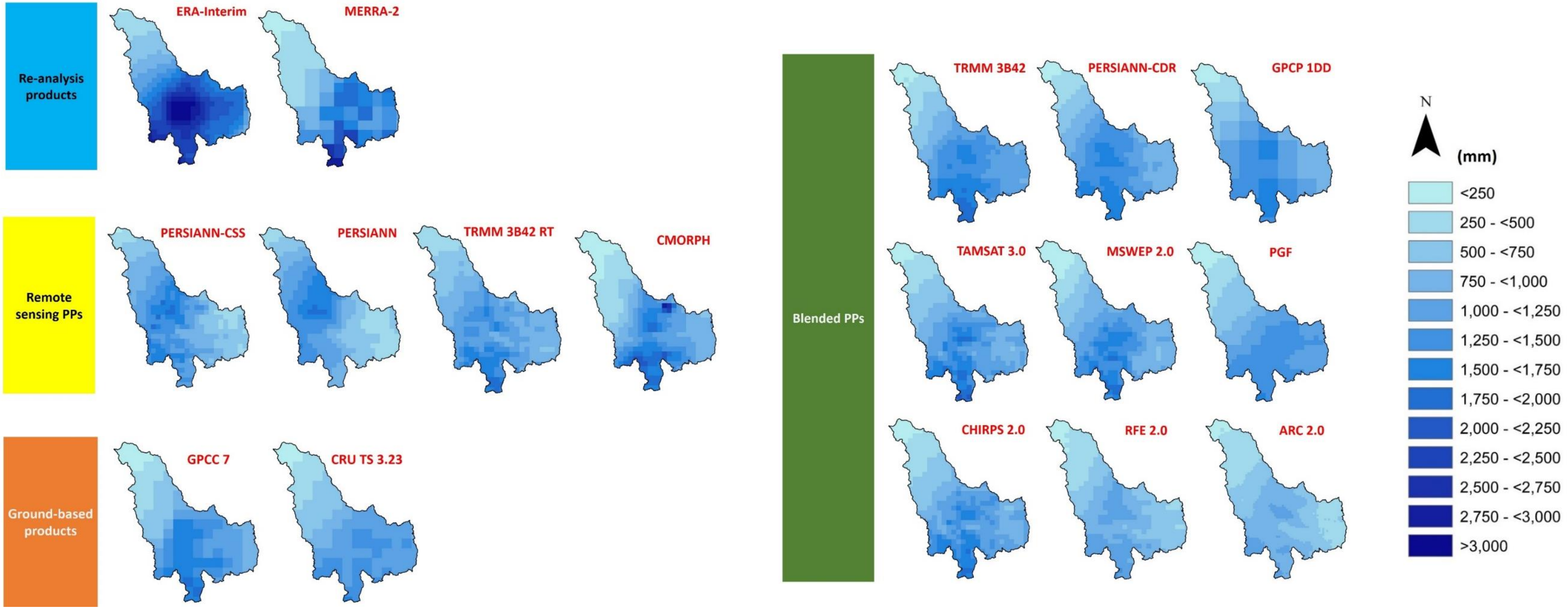
Source: Khalifa et. al. (2020a)

40+

Public-domain precipitation products

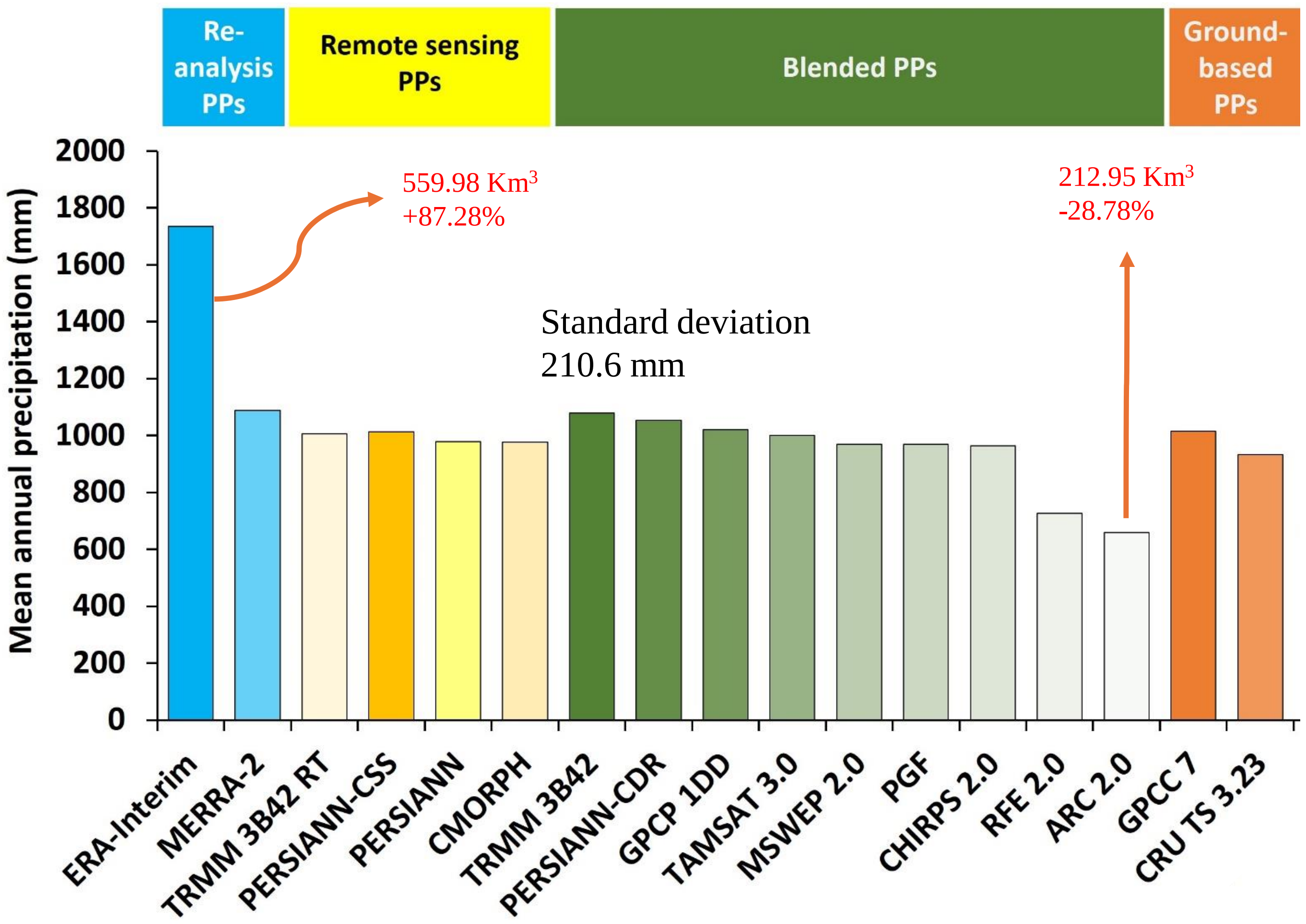


Source: Khalifa et. al. (2020a)



Source: Khalifa et. al. (2020a)

Multi-year mean precipitation over the Blue Nile Basin (2001-2005)



Total area of the basin
322,903 km^2

Total water
299 billion m^3
(Bastiaanssen et al., 2014)

- Large variation
- Performance needs to be checked!
- Correct bias

Source: Khalifa et. al. (2020a)

- 2. Categorize landuse classes into four main classes

Conserved land use	Utilised land use	Modified land use	Managed water use
Reserves or national parks	Closed natural forests	Plantation trees	Irrigated pastures
Areas set aside for conservation	Tropical rain forest	Rainfed pastures	Irrigated crops
Glaciers	Open natural forest	Rainfed crops	Irrigated fruits
Coastal protection sites	Woody savanna	Rainfed fruit	Irrigated biofuels
	Open savanna	Rainfed biofuels	Reservoirs & canals
	Sparse savanna	Rainfed recreational parks	Greenhouses
	Shrub land	Fallow land	Aquaculture
	Natural pastures	Dump sites	Residential areas & homesteads
	Deserts	Oasis & wadis	Industrial areas
	Mountains	Roads and lanes	Irrigated recreational parks
	Rocks	Peri-urban areas	Managed wetlands & swamps
	Flood plains		Inundation areas
	Tidal flats		Mining
	Bare land		Evaporation ponds
	Waste land		Waste water treatment beds
	Moore fields		Power plants
	Wetlands & swamps		
	Alien invasive species		
	Permafrosts		

After Karimi et. al., 2014b

- 3. Assignment of precipitation and ET to these four land use classes

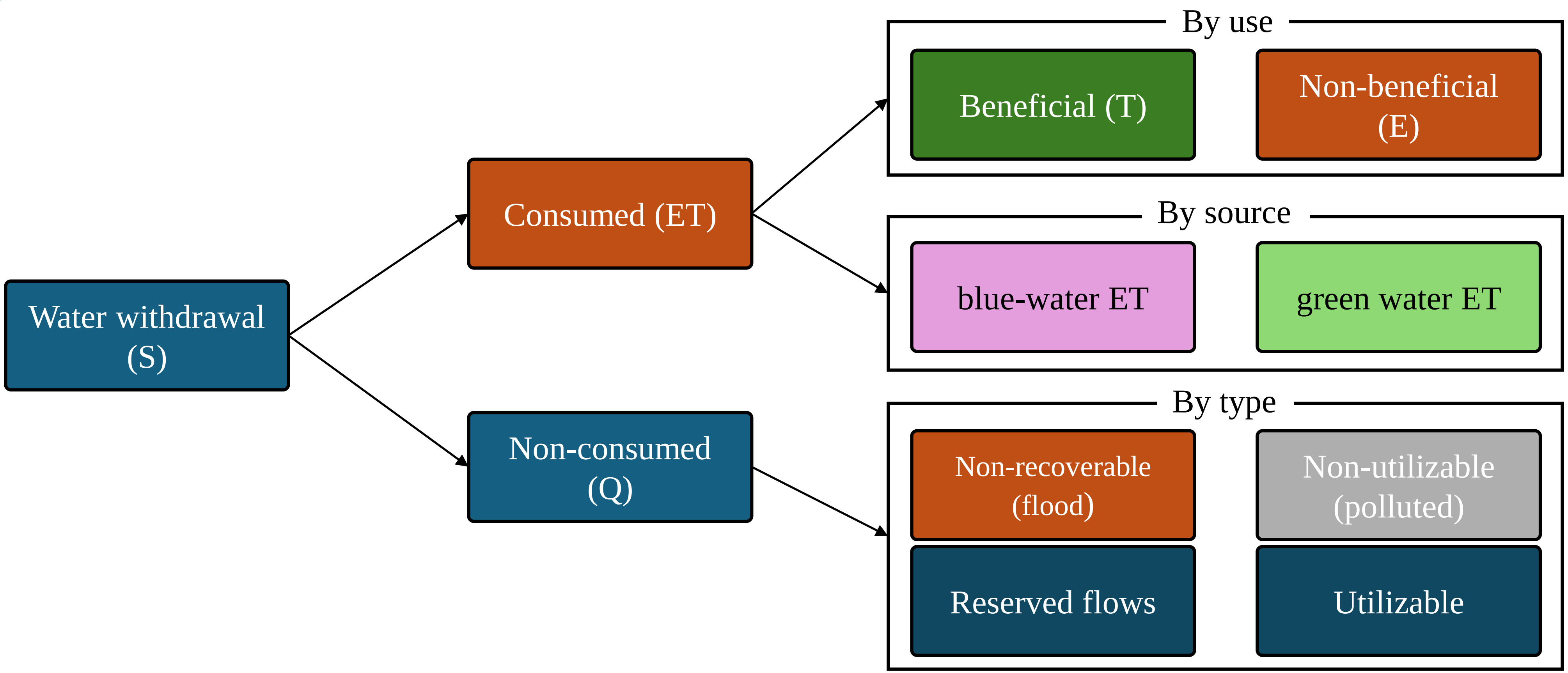
Table 2: The average $P - ET_a$ for each land cover class for the hydrological years from 2010 to 2018 in the Jordan River Basin.

Land Cover Class Description	Area (km²)	Area percentage (%)	P (mm/year)	P (mm³/year)	ET_a (mm/year)	ET_a (mm³/year)	$P - ET_a$ mm/year)	$P - ET_a$ (mm³/year)
Bare / sparse vegetation	21,586	50.0%	154	3,332	37	796	118	2,536
Grassland	7,191	16.6%	320	2,302	190	1,368	130	934
Cropland, fallow	4,686	10.8%	215	1,010	94	441	121	569
Built-up	1,092	2.5%	320	350	173	189	147	161
Cropland, rainfed	4,883	11.3%	389	1,900	379	1,850	10	50
Shrub land	1,207	2.8%	447	540	411	496	37	44
Tree cover: open, evergreen needle-leaved	1	< 0.1%	635	1	649	1	-15	< - 1
Shrub or herbaceous cover, flooded	2	< 0.1%	438	1	459	1	-21	< - 1
Tree cover: closed, deciduous broadleaved	< 1	< 0.1%	640	< 1	1,029	< 1	-389	< - 1
Tree cover: open, deciduous broadleaved	< 1	< 0.1%	641	< 1	1,072	1	-430	< - 1
Tree cover: closed, evergreen needle-leaved	24	0.1%	690	17	742	18	-53	-1
Tree cover: closed, mixed type	4	< 0.1%	718	2	1,137	4	-419	-1
Tree cover: open, unknown type	558	1.3%	481	268	519	289	-38	-21
Tree cover: closed, unknown type	101	0.2%	529	53	911	92	-382	-38
Cropland, irrigated or under water management	847	2.0%	299	253	555	470	-257	-217
Water bodies	1,057	2.4%	163	172	1,258	1,329	-1,095	-1,157
Total	43,238	100.0%	-	10,201	-	7,343	-	2,848

FAO and IHE Delft (2020)

Assignment of ET to these four land use classes is very helpful to evaluate the manageable and unmanageable water depletions (Karimi et. al., 2013b).

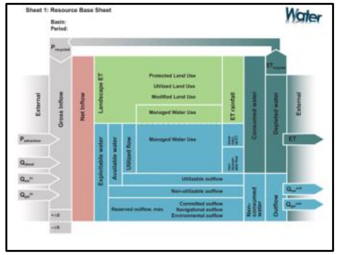
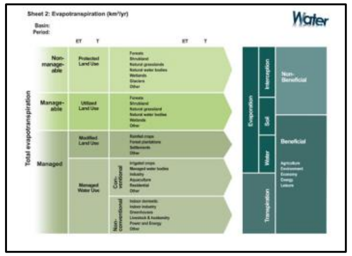
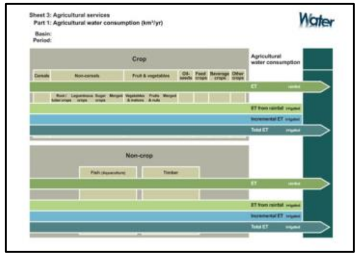
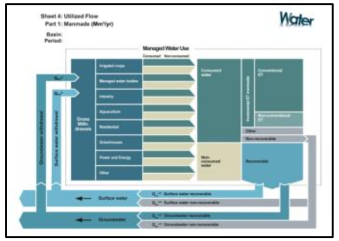
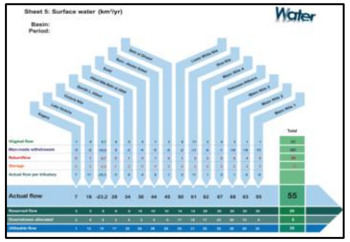
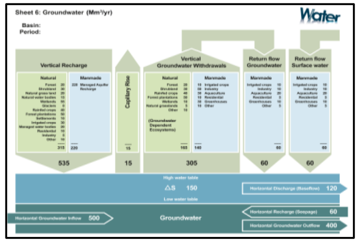
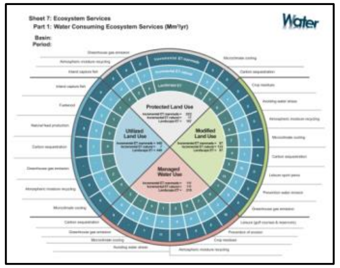
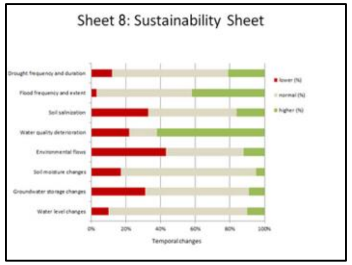
- 4. Estimate water consumption



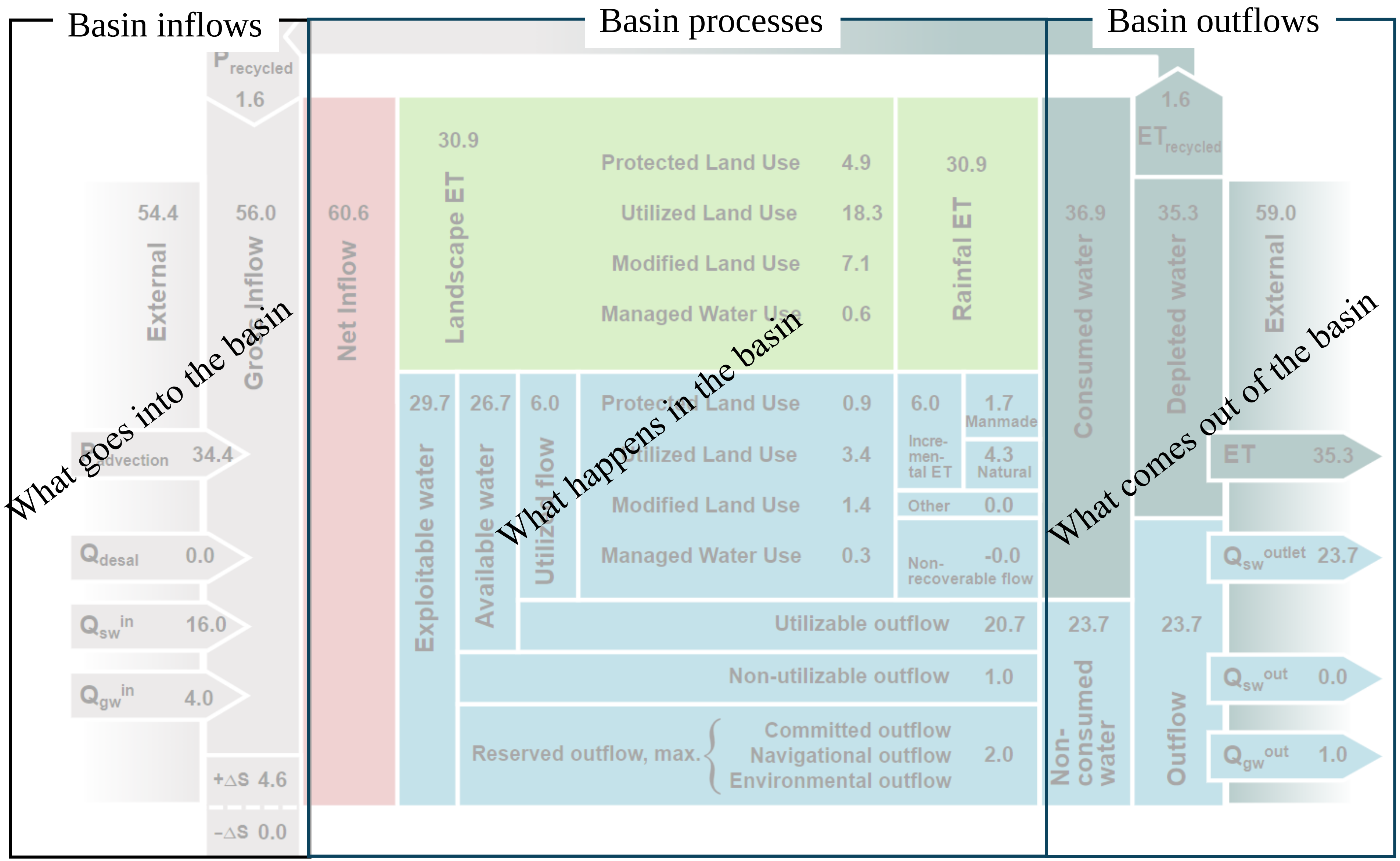
Source: Naga Velpuri (IWMI)

• 5. Development of WA+ sheets

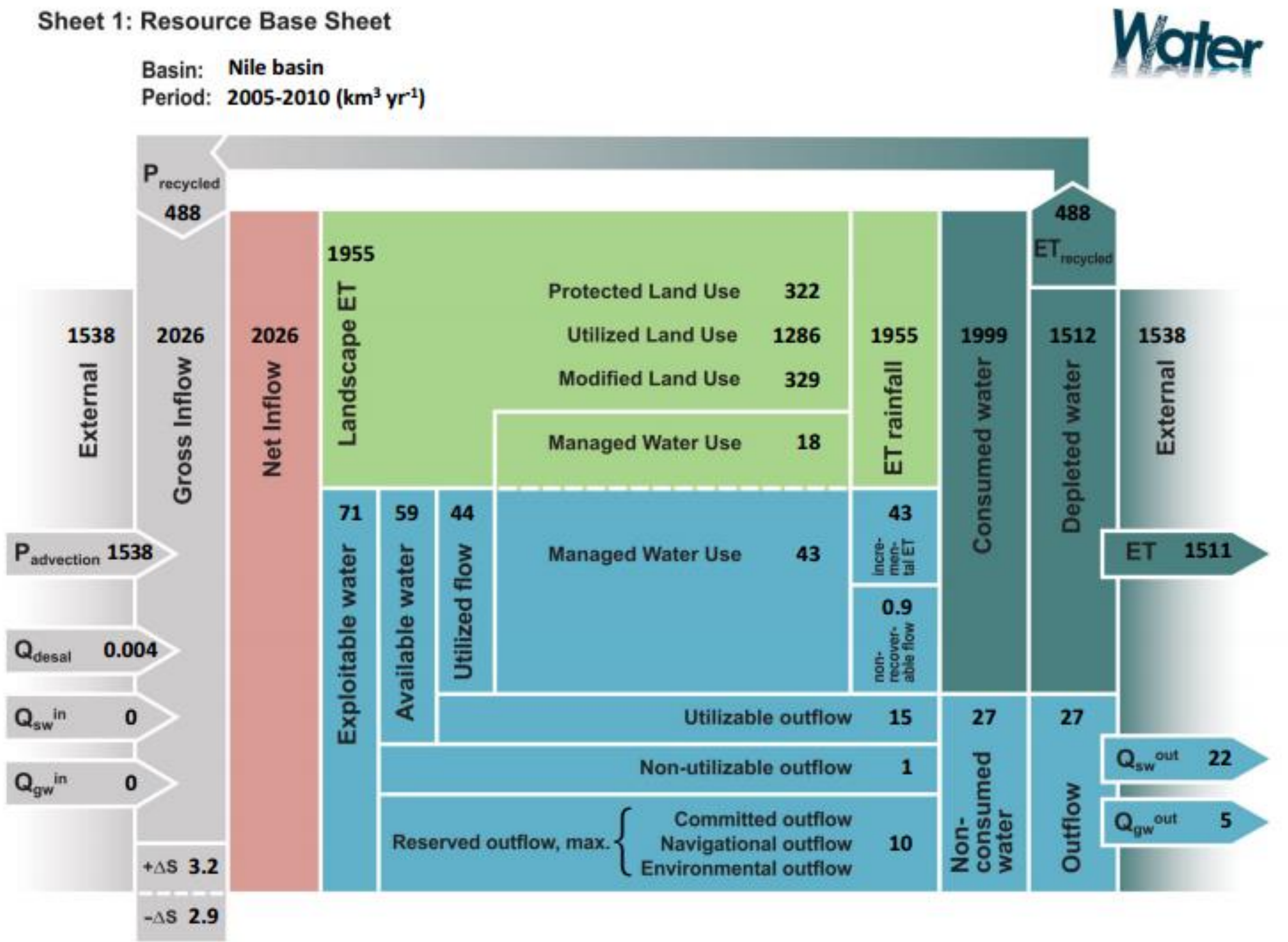
1. Resource Base
2. Evapotranspiration
3. Agricultural Services
4. Utilized Flow
5. Surface Water
6. Groundwater
7. Ecosystem Services
8. Sustainability

Water Accounts help the user to understand:

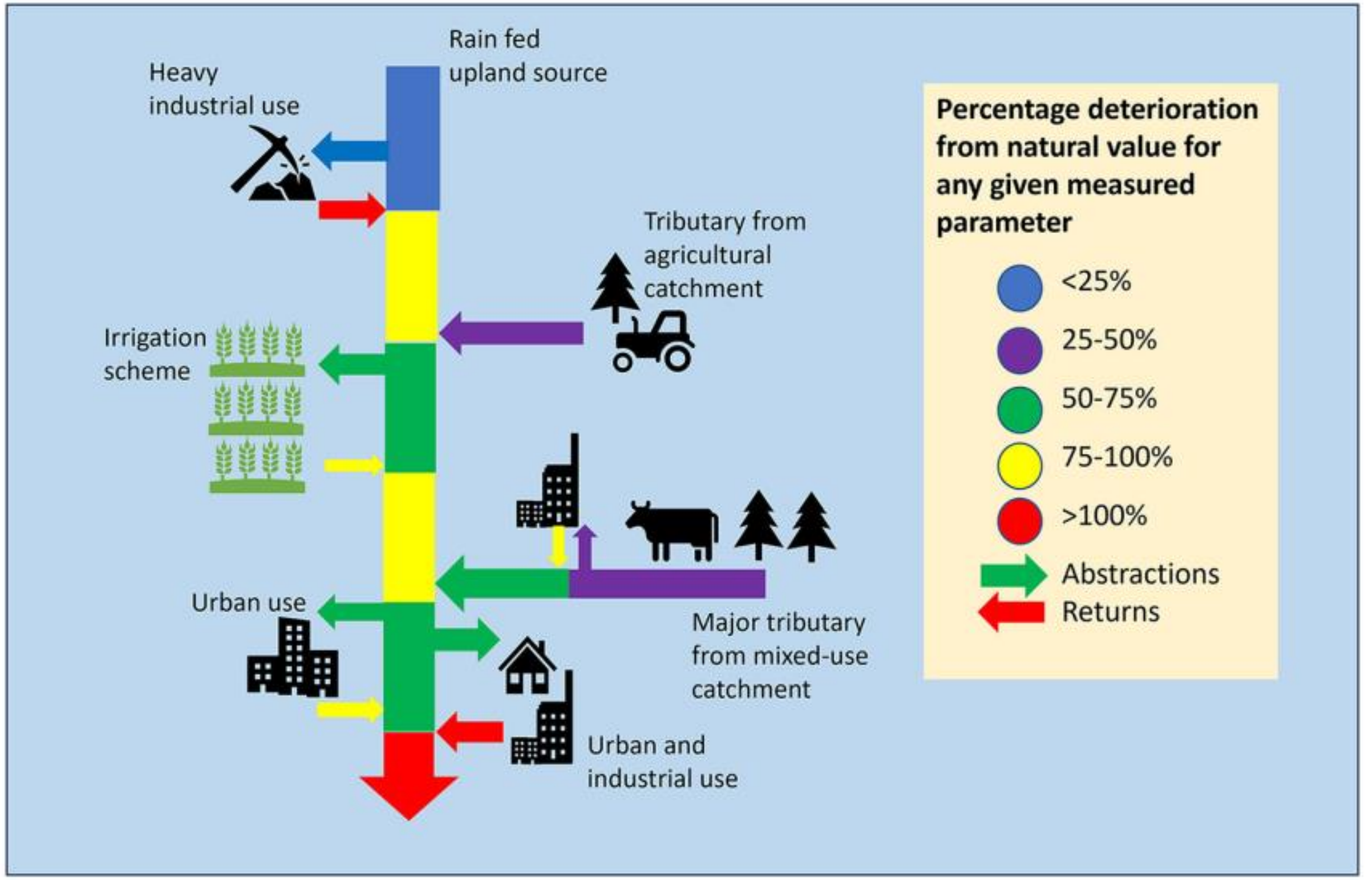


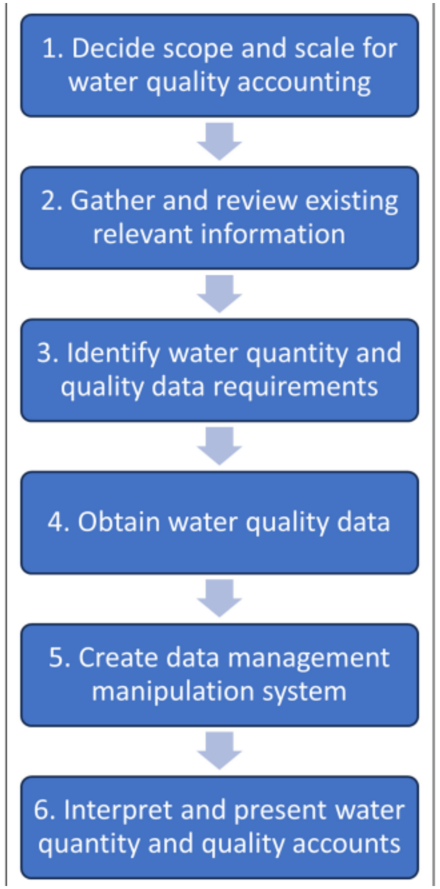
Source: Naga Velpuri (IWMI)



- Quantify agricultural water demands and deficits.
- Understand the potential of water reuse.

Linking water accounting and water quality monitoring





"Incorporating water quality monitoring into water accounting projects could have the potential to improve overall management of ambient freshwater"

Source: Karimi et al. (2024)

• 6. Develop performance indicators

Indicators	Definition
Exploitable water fraction	Exploitable water divided by the net inflow
Storage change fraction	Freshwater storage change divided by exploitable water
Available water fraction	Available water divided by exploitable water
Basin closure fraction	Utilized flow divided by available water
Reserved flow fraction	Reserved outflows divided by the total outflow
T fraction	Total T divided by the total ET
Beneficial fraction	Beneficial E and T divided by the total ET
Managed fraction	Managed ET divided by the total ET
Agri. ET fraction	Agricultural ET divided by the total ET
Irri. ET fraction	Irrigated agricultural ET divided by the agricultural ET
Land productivity$_{\text{crops}}$	Crop biomass times harvest index divided by cropped area
Land productivity$_{\text{pastures}}$	Pastures biomass times harvest index divided by pasture area
Water productivity$_{\text{crops rainfed}}$	Rainfed crops biomass times harvest index divided by rainfed crops ET
Water productivity$_{\text{crops irrigated}}$	Irrigated crops biomass times harvest index divided by Irrigated crops ET
Food Irri. Dependency	Irrigated food production divided by total food production
GW withdrawal fraction	Groundwater withdrawals divided by total withdrawals
Classical irrigation efficiency	Incremental ET of agriculture divided by withdrawals for agriculture
Recoverable fraction	Return flow divided by total withdrawals

Karimi et. al. (2013b)

Table 9: WA+ Sheet 1 key indicators of Jordan River Basin for the hydrological years from 2010 to 2018 based on water balance derived from WaPOR datasets.

Year	ET fraction (%)	Stationarity index (%)	Basin Closure (%)	Available water (km^3/year)	Managed water (km^3/year)	Managed fraction (%)
2010	83.8	17.7	98.6	2.58	0.79	30.5
2011	89.6	9.2	97.9	1.70	0.77	45.4
2012	75.6	29.7	98.1	3.09	0.71	22.9
2013	69.7	40.4	97.9	4.15	0.72	17.3
2014	73.8	33.0	98.2	3.29	0.79	24.0
2015	77.1	28.9	99.3	3.35	0.90	26.7
2016	82.2	21.4	99.8	2.62	0.88	33.7
2017	83.7	19.1	99.6	2.42	0.91	37.6
2018	75.4	32.4	99.8	3.59	0.79	21.9
Average	79.0	25.8	98.8	2.98	0.81	28.9

FAO and IHE Delft (2020)

- 7. Explore alternative management scenarios

Scenario	Action	Real water saving ($km^3 yr^{-1}$)	WA+ indicators
A Mixed actions	Reduce *E* rainfed land by 5 % Reduce *E* irrigated land by 15 % Reduce irrigated area by 0 % Biomass production increase 5 % Harvest index increase 5 % Reduce utilizable flow by 50 %	12.6	Storage change fr.: −0.17 Reserved flow fr.: 0.73 *T* fr.: 0.48 Beneficial fr.: 0.53 Land productivity $_{irri}$: 8,560 Land productivity $_{rainfed}$: 1,030 Water productivity $_{irri}$: 0.90 GW withdrawal fr.: 0.41
B Reduce *E*	Reduce *E* rainfed land by 15 % Reduce *E* irrigated land by 35 % Reduce irrigated area by 0 % Biomass production increase 5 % Harvest index increase 10 % Reduce utilizable flow by 75 %	37.8	Storage change fr.: −0.02 Reserved flow fr.: 0.85 *T* fr.: 0.50 Beneficial fr.: 0.55 Land productivity$_{irri}$: 9300 Land productivity$_{rainfed}$: 1130 Water productivity$_{irri}$:1.09 GW withdrawal fr.: 0.32
C Modify area	Reduce *E* rainfed land by 5 % Reduce *E* irrigated land by 15 % Reduce irrigated area by 15 % Biomass production increase 5 % Harvest index increase 10 % Reduce non-utilizable flow by 75 %	39.4	Storage change fr.: −0.01 Reserved flow fr.: 0.85 *T* fr.: 0.45 Beneficial fr.: 0.50 Land productivity$_{irri}$: 9300 Land productivity$_{rainfed}$: 1,130 Water productivity y_{irri}: 0.93 GW withdrawal fr.: 0.30

Karimi et. Al. (2013b)

Case 1: Botswana

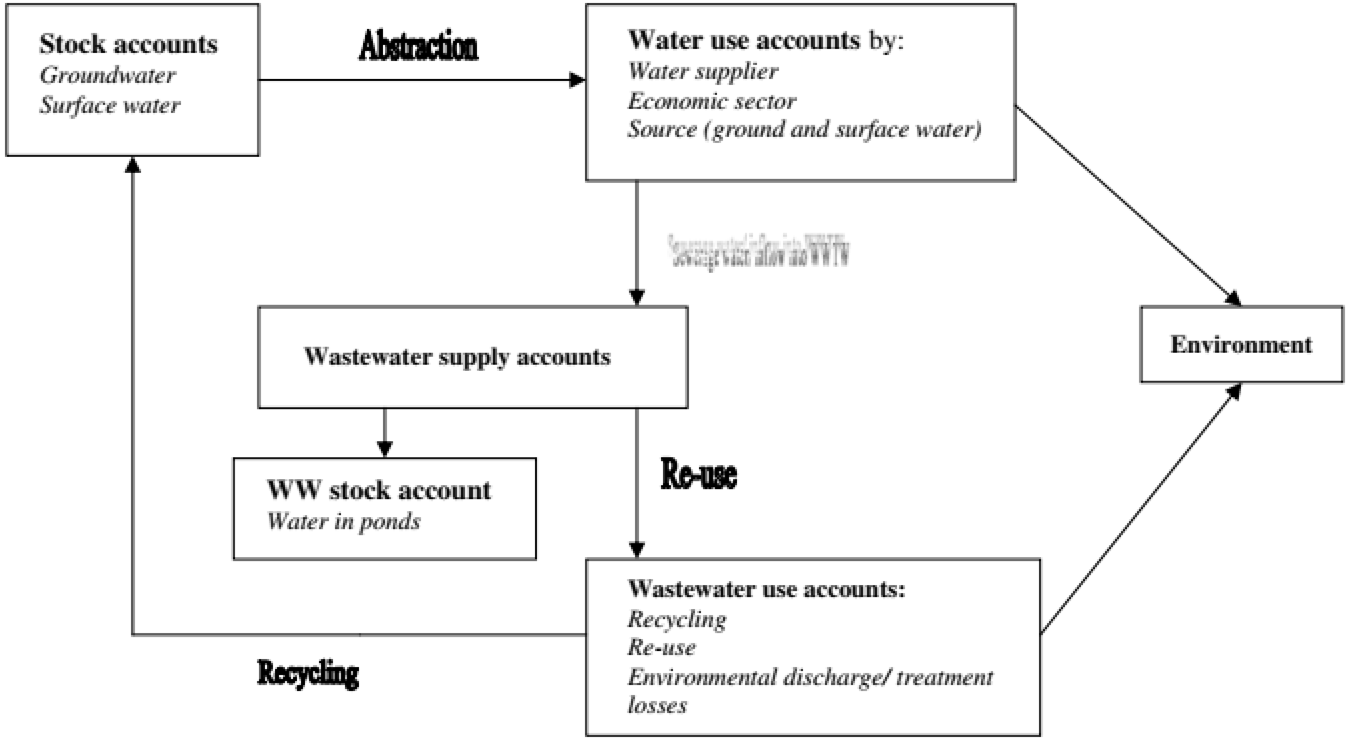


Fig. 1. Linkages between different accounts.

After Arntzen and Setlhogil (2007)

Table A5

Wastewater use accounts (1990–2003; 000 m^3)

	User category	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
I	Agriculture	320	335	332	349	334	401	417	459	480	554	531	600
II	Mining	214	212	234	227	233	232	236	257	253	259	302	318
III	Industry	0	0	0	0	0	0	0	0	0	0	0	0
IV	Water/electricity	0	0	0	0	0	0	0	0	0	0	0	0
V	Construction	0	0	0	0	0	0	0	0	0	0	0	0
V	Services	141	146	176	167	164	168	210	237	244	256	302	302
VI	Government												
	Central govt	141	146	176	167	164	168	210	237	244	256	302	302
	Local govt	71	71	78	76	78	77	79	86	84	86	101	106
VI	Domestic Use	0	0	0	0	0	0	0	0	0	0	0	0
VII	Environment												
VII.1	Evaporation/treatment losses	6127	6232	7301	7164	7055	7480	8714	9785	10 540	10 591	11 724	11 942
VII.2	Discharge in rivers	6880	7144	8362	8148	8060	8528	10 093	11 535	12 466	13 932	15 126	15 497
	Other outflow	34	38	42	51	47	54	38	51	60	67	65	72
VIII	Total use of WW	13 929	14 325	16 700	16 348	16 135	17 109	19 995	22 648	24 372	26 002	28 453	29 138

Table 5

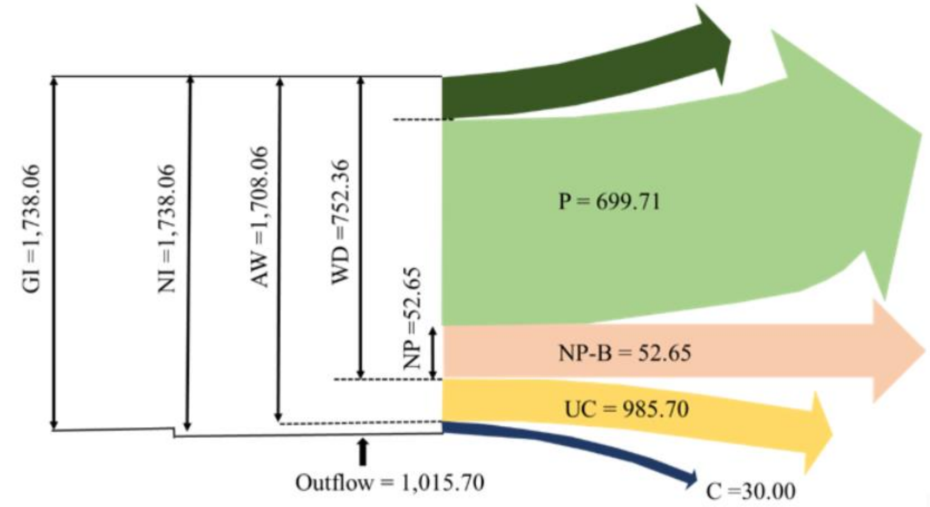
Possible direct gross economic benefits of a multiple WW re-use example

Destination	Designated re-use amount of WW (Mm^3)	Value added/m^3 (93/94 P/m^3)	Directly associated value added of re-use (M Pula 93/94 prices)	Possible associated paid employment
Irrigated agriculture	8.0	20	160	50–500
Construction	0.2	2468	494	7000–12 000
Government	1.0	271	271	20 000–25 000
Domestic use	5.3	0	None[a]	
Total	14.5		925	Around 40 000

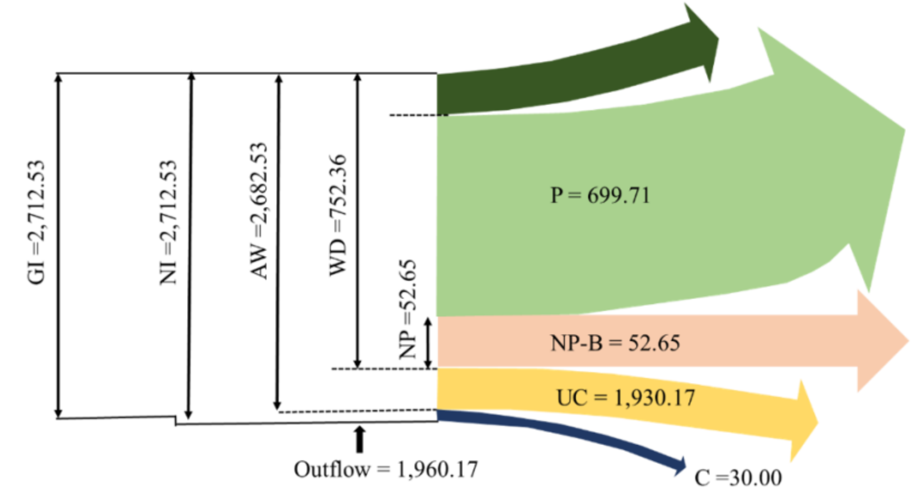
[a] The benefits of re-use in the domestic sector depend on the destination of the saved fresh water sources, and could be substantial.

After Arntzen and Setlhogil (2007)

Case 2: Samut Prakan Province, Thailand



Annual water accounts



Annual water accounts including wastewater supply

Treating wastewater for reuse was more costly than producing municipal water. Nevertheless, wastewater reuse can contribute to environmental and health benefits.

After Tingsa et. al. (2007)

Key message

- Notably, integrating water quality considerations offers benefits not only for water quality itself but also for overall water quantity management.
- Water Accounting Plus (WA+), with its comprehensive approach, holds significant promise in bridging this crucial linkage.
- Considering wastewater in water accounting has the potential to address prevailing water scarcity challenges in the region and mitigate the looming impacts of climate change.
- In the Gulf region, WA+ presents a pivotal opportunity to harness untapped wastewater resources, serving as a foundational framework for sustainable development.

Thank you!

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